



(12)

EUROPEAN PATENT SPECIFICATION

(45) Date of publication and mention  
of the grant of the patent:  
01.12.1999 Bulletin 1999/48

(21) Application number: 95903889.4

(22) Date of filing: 22.12.1994

(51) Int. Cl.<sup>6</sup>: A61K 39/39

(86) International application number:  
PCT/IB95/00013

(87) International publication number:  
WO 95/17211 (29.06.1995 Gazette 1995/27)

(54) NON-TOXIC MUCOSAL ADJUVANT

NICHTTOXISCHES SCHLEIMHAUTADJUVANS  
ADJUVANT NON TOXIQUE POUR LES MUQUEUSES

(84) Designated Contracting States:  
AT BE CH DE DK ES FR GB GR IE IT LI LU MC NL  
PT SE

(30) Priority: 22.12.1993 GB 9326174  
24.03.1994 WO PCT/IB94/00068

(43) Date of publication of application:  
25.09.1996 Bulletin 1996/39

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## Description

## FIELD OF THE INVENTION

[0001] The present invention relates to an adjuvant useful for the administration of vaccines to organisms. In particular, the adjuvant of the invention allows the delivery of vaccines to mucosal surfaces to raise a secretory and systemic immune response.

## BACKGROUND TO THE INVENTION

[0002] Current vaccination technology is based almost exclusively on systemic vaccination techniques wherein the vaccine is injected into the subject to be vaccinated. Only certain live/attenuated vaccines, such as the Sabin polio vaccine, may be taken orally.

[0003] The advantages of oral immunisation techniques are several fold. For instance, it is self-evident that a vaccine which may be fed to subjects is easier to administer on a large scale in the absence of specialised equipment, especially to subjects which may be difficult to handle or even locate, such as livestock and wild animals. The spread of infection by the re-use of needles in developing countries would thereby be avoided. Furthermore, an oral vaccine may be provided in the form of an edible solid, which is easier to handle under extreme conditions and is more stable than liquid suspensions as currently used.

[0004] Moreover, delivery of immunogens to a mucosal membrane, such as by oral or intranasal vaccination, would permit the raising of a secretory immune response.

[0005] The secretory immune response, mainly IgA-mediated, appears to be substantially separate from the systemic immune response. Systemic vaccination is ineffective for raising a secretory immune response. This is a considerable disadvantage when considering immunisation against pathogens, which often enter the subject across a mucosal surface such as the gut or lung.

[0006] Unfortunately, it is not possible to raise a secretory immune response to the vast majority of antigens simply by exposing mucosal surfaces to such antigens. Furthermore, no adjuvant capable of eliciting a secretory immune response to a given antigen is currently available.

[0007] The apparent difficulty is largely due to a phenomenon known as oral tolerance. The linings of the gut and the lungs are naturally tolerant to foreign antigens, which prevents an immune response being raised to ingested or inhaled substances, such as food and airborne particulate matter.

[0008] The ADP-ribosylating bacterial toxins, namely diphtheria toxin, pertussis toxin (PT), cholera toxin (CT), the *E. coli* heat-labile toxin (LT1 and LT2), *Pseudomonas* endotoxin A, *C. botulinum* C2 and C3 toxins as well as toxins from *C. perfringens*, *C. spirillum* and *C. difficile* are potent toxins in man. These toxins are composed of a monomeric, enzymatically active A subunit which is responsible for ADP-ribosylation of GTP-binding proteins, and a non-toxic B subunit which binds receptors on the surface of the target cell and delivers the A subunit across the cell membrane. In the case of CT and LT, the A subunit is known to increase intracellular cAMP levels in target cells, while the B subunit is pentameric and binds to GM1 ganglioside receptors.

[0009] In 1975 and 1978 observations were made which demonstrated that CT is able to induce mucosal and systemic immunity against itself when administered intraduodenally (i.e. to a mucosal surface). The membrane-binding function of CT was shown to be essential for mucosal immunogenicity, but cholera toxinol, also known as the B subunit of CT (CTB) was inactive in isolation (Pierce and Gowans, *J. Exp. Med.* 1975; 142: 1550; Pierce, *J. Exp. Med.* 1978; 148: 195-206).

[0010] Subsequently, it was demonstrated that CT induces systemic and mucosal immunity to co-administered antigens, in other words functions as a mucosal adjuvant (Elson, *Curr. Top. Microbiol. Immunol.* 1989; 146: 29; Elson and Ealding, *J. Immunol.* 1984; 133: 2892-2897; Elson and Ealding, *Ibid.* 1984; 132: 2736-2741; Elson *et al.*, *J. Immunol. Methods* 1984; 67: 101-118; Lycke and Homgren, *Immunology* 1986; 59: 301-338).

[0011] The experiments referred to above were conducted in mice, which are comparatively resistant to the toxic effects of CT. In contrast, wild-type CT is extremely toxic to humans, rendering the use of CT having any substantial residual toxicity as a mucosal adjuvant in humans entirely out of the question.

[0012] Two approaches have been taken in the prior art to address the problem of CT toxicity. The first approach has involved the use of CTB as a mucosal adjuvant. CTB is entirely non-toxic.

[0013] In one series of experiments, CTB was covalently coupled to horseradish peroxidase (HRP) and administered to mice intraduodenally. This gave rise to a powerful mucosal immune response to HRP (McKenzie and Halsey, *J. Immunol.* 1984; 133: 1818-1824).

[0014] This result has subsequently been partially confined with other antigens (Liang *et al.*, *J. Immunol.* 1988; 141: 1495-1501; Czerkinsky *et al.*, *Infect. Immun.* 1989; 57: 1072-1077). The same principle has also been established to be effective when chimeric antigens produced by gene fusion to sequences encoding CTB have been tested (Dertz-

baugh and Elson, *Infect. Immun.* 1993; **61**: 384-390; Dertzbaugh and Elson, *ibid.* 1993; **61**: 48-55; Sanchez *et al.*, *Res. Microbiol.* 1990; **141**: 971-979; Holmgren *et al.*, *Vaccine* 1993; **11**: 1179-1184).

[0015] However, the production of chimeric or coupled antigens introduces a further step in the preparation of suitable vaccines, which essentially requires that antigens be prepared in a form conjugated with CTB especially for oral use. It would be for simpler and more economical if the adjuvant could be administered in simple admixture with the antigen.

[0016] An adjuvant effect for co-administered CTB has been alleged in a number of publications (Tamura *et al.*, *J. Immunol.* 1992; **149**: 981-988; Hirabayashi *et al.*, *Immunology* 1992; **75**: 493-498; Gizurarson *et al.*, *Vaccine* 1991; **9**: 825-832; Kikuta *et al.*, *Vaccine* 1970; **8**: 595-599; Hirabayashi *et al.* *ibid.* 1990; **8**: 243-248; Tamura *et al.*, *ibid.* 1989; **7**: 314-322; Tamura *et al.*, *ibid.* 1989; **7**: 257-262; Tamura *et al.*, *ibid.* 1988; **6**: 409-413; Hirabayashi *et al.*, *Immunology* 1991; **72**: 329-335 Tamura *et al.*, *Vaccine* 1989; **7**: 503-505).

[0017] However, a number of aspects of the observations reported above were not entirely convincing. For example, it was noted that the adjuvant effect ascribed to CTB was not H-2 restricted, it is known, however, that immune response to CTB is H-2 restricted (Elson and Ealring, *Eur. J. Immunol.* 1987; **17**: 425-428). Moreover, the alleged adjuvant effect was observed even in individuals already immune to CTB.

[0018] Other groups were unable to observe any mucosal adjuvant effect attributable to CTB (Lycke and Holmgren, *Immunology* 1986; **59**: 301-308; Lycke *et al.*, *Eur. J. Immunol.* 1992; **22**: 2277-2281). Experiments with recombinant CTB (Holmgren *et al.*, *Vaccine* 1993; **11**: 1179-1183) confirmed that the alleged effect is largely if not exclusively attributable to low levels of contamination of CTB preparations with CT.

[0019] Thus, it is presently accepted that CTB is not useful as a mucosal adjuvant.

[0020] A second approach to eliminating the toxicity of CT has been to mutate the CT holotoxin in order to reduce or eliminate its toxicity. The toxicity of CT resides in the A subunit and a number of mutants of CT and its homologue, LT, comprising point mutations in the A subunit are known in the art. See, for example, International Patent Application W092/19265 (Amgen). It is accepted in the art that CT and LT are generally interchangeable, showing considerable homology.

[0021] However, the only mutant so far tested for mucosal adjuvant activity, an LT mutant having a Glu-Lys mutation at position 112, was found to be inactive as a mucosal adjuvant (Lycke *et al.*, *Eur. J. Immunol.* 1992; **22**: 2277-2281; Holmgren *et al.*, *Vaccine* 1993; **11**: 1179-1183). The authors of these publications conclude that there is a link between the ADP-ribosylating activity of CT and/or LT and the adjuvant activity. It appears from these publications, therefore, that CTB or a non-toxic mutant of CT or LT would not be active as a mucosal adjuvant.

[0022] W095/09649 (Medeva Holdings BV) discloses the use of a non-toxic double mutant form of pertussis toxin for the manufacture of an adjuvant composition for stimulating or enhancing a protective immune response of an antigen co-administered therewith.

## SUMMARY OF THE INVENTION

[0023] There therefore remains a need for an active mucosal adjuvant which may be used to increase the immunogenicity of an antigen when administered to a mucosal surface, such as orally or intranasally.

[0024] It has now been discovered that, in complete contradiction with the results and conclusions presented in the prior art, the toxic and adjuvant activities of the ADP-ribosylating toxins are separable. An entirely non-toxic mutant of such a toxin has been shown to be active as a mucosal adjuvant.

[0025] It has been demonstrated that an LT mutant which completely lacks toxicity is active as a mucosal adjuvant and protects subjects against subsequent challenge with a lethal dose of the immunogen. Although the Applicants do not wish to be bound by any particular theory, it is postulated that the results of Lycke *et al.* and Holmgren *et al.* quoted above may be contradicted at least in part because they fail to take into account the stability of the mutant being made.

*Inter alia* by ensuring that the non-toxic mutant of the invention is stable at the site of delivery, it has been demonstrated that the adjuvant effect of CT and/or LT may be maintained while its toxic effects are eliminated.

[0026] In a first aspect, the present invention provides a pharmaceutical composition comprising a non-toxic mucosal adjuvant in admixture with a second antigen, characterised in that said non-toxic mucosal adjuvant is a detoxified bacterial ADP-ribosylating toxin having a tautant A subunit (provided that said non-toxic mucosal adjuvant is not a non-toxic double mutant form of pertussis toxin - see W095/09649).

[0027] The detoxified bacterial ADP-ribosylating toxin preferably comprises one or more amino acid additions, deletions or substitutions.

[0028] Particularly suitable are detoxified mutants of CT or LT. For example, a mutant LT in accordance with the invention may possess an Arg7 to Lys7 substitution at position 7 of the A subunit, the so-called LTK7 mutant.

[0029] Alternative mutants are known to those skilled in the art and are preferred molecules for use in the present invention. Examples include PT mutated at position 129, in particular PT having a Glu 129->Gly mutation. Further mutants include PT mutated at one or both of Trp 26 and Arg 9, optionally in combination with the Glu 129 mutation.

[0030] The mutant used in the invention may moreover be a mutant wherein the mutation has been effected in a part

of the molecule which results in the prevention of proteolytic cleavage of the A subunit of the toxin, such that enzymatic activity is not brought about. Such mutants are described in Grant *et al.* *Inf. and Immunity* (1994) 62(10) 4270-4278. For example, the mutant may comprise an Arg 192→Gly mutation in LT or a corresponding mutation in another ADP-ribosylating toxin.

[0031] The mutant of the invention is preferably in the form of a holotoxin, comprising the mutated A subunit and the B subunit, which may be oligomeric, as in the wild-type holotoxin. The B subunit is preferably not mutated. However, it is envisaged that a mutated A subunit may be used in isolation from the B subunit, either in an essentially pure form or complexed with other agents, which may replace the B subunit and/or its functional contribution.

[0032] Methods for the design and production of mutants of CT and/or LT are known in the art. Suitable methods are described in International Patent Application W093/13202 (Biocine Sclavo), as well as W092/19265 (Amgen).

[0033] The adjuvant of the invention is preferably administered in admixture with a suitable antigen against which it is desired to raise an immune response. If the antigen and the adjuvant are not in admixture, it is preferred that they be administered within a relatively short time of each other, at the same site of administration. It has been observed that the adjuvant effect provided by wild-type CT is short lived (see Lycke and Homgren, *Immunology* 1986; 59: 301-308). In an alternative embodiment, the mucosal adjuvant of the invention may be administered, optionally in isolation from other antigens, as a boost following systemic or mucosal administration of a vaccine.

[0034] The precise formulation of the vaccine may vary in accordance with the nature of the immunogen. For example, if the antigen is enclosed in slow-releasing microspheres to liposomes, the mucosal adjuvant may be similarly enclosed so that the antigen and the adjuvant may interact simultaneously with the mucosal immune system. Alternatively, separate mucosal administration of the adjuvant of the invention may be used to enhance mucosal response to parentally-administered vaccines.

[0035] In a second aspect, the present invention provides the use of a non-toxic mutant of CT or LT as a mucosal adjuvant in the preparation of a composition for mucosal administration.

[0036] Preferably, the composition is a vaccine and is useful for the immunisation of a subject against a disease or the treatment of a subject suffering from a disease.

[0037] Preferably, the mutant comprises one or more amino acid additions, substitutions or deletions in the amino acid sequence of the A subunit of CT or LT which is or are effective to abolish the toxicity of the toxin.

[0038] According to a third aspect of the invention, there is provided the use of a non-toxic mucosal adjuvant and a second antigen during the manufacture of a vaccine, provided that said non-toxic mucosal adjuvant is not a non-toxic double mutant form of pertussis toxin.

[0039] The mucosal surface may be any suitable mucosal surface of the subject. For example, the administration may be carried out by inhalation, by means of a rectal or vaginal suppository, or a pessary, by feeding or other buccal administration, by means of an aerosol, by intranasal delivery or direct application to mucosal surfaces. Especially preferred are oral and intranasal administration.

[0040] The subject may be any organism susceptible to immunisation. Especially indicated are humans and other mammals such as livestock, pets and wildlife.

[0041] Diseases against which the subject may be immunised include all diseases capable of being treated or prevented by immunisation, including viral diseases, allergic manifestations, diseases caused by bacterial or other pathogens which enter through or colonise mucosal surfaces, AIDS, autoimmune diseases such as systemic Lupus Erythematosus, Alzheimer's disease and cancers. Examples of viral infections which may be treated or prevented using the invention include infection by DNA viruses, such as EBV and VZV, and in particular herpesviridae, for example HSV and HCMV, adenoviridae, papovaviridae, such as HPV, hepatitis B virus, such as HBV, infection by RNA viruses, such as picornaviridae, especially poliovirus and HAV, rhinoviridae and FMDV, togaviridae, flaviviridae, coronaviridae, paramyxoviridae, such as RSV, orthomyxoviridae, such as influenza virus, and retroviridae, especially HIV. Vaccination against HCV and HDV is also envisaged.

[0042] Examples of bacterial infections suitable for treatment or prophylaxis by the invention include infection with *Helicobacter pylori*, streptococci, meningococcus A, B, and C, *Bordetella pertussis* and *Chlamydia* and *Typhoid*.

[0043] Vaccine formulation suitable for delivery at mucosal surfaces may be prepared as set out hereinbelow, while further formulations will be apparent to those of skill in the art. Suitable administration regimes are, likewise, set out below while modifications of the exemplified values will be apparent to those of skill in the art.

[0044] Moreover, the invention provides a mutant of CT or LT which is a non-toxic mucosal adjuvant and a second antigen for simultaneous separate or sequential administration. Simultaneous administration of the adjuvant and the second antigen when combined in a single vehicle, carrier or particle, as exemplified below, is particularly preferred.

[0045] The second antigen may be any antigen to which it is desired to raise an immune response in the subject. Suitable antigens comprise bacterial, viral and protozoan antigens derived from pathogenic organisms, as well as allergens, allogens and antigens derived from tumours and self-antigens. Typically, the antigen will be a protein, polypeptide or peptide antigen, but alternative antigenic structures, such as nucleic acid antigens, carbohydrate antigens, and whole or attenuated or inactivated organisms such as bacteria, viruses or protozoa are not excluded. The invention fur-

ther provides a method for the manufacture of an adjuvanted vaccine comprising the steps of:

- a) performing site-directed mutagenesis on the A-subunit of a bacterial ADP-ribosylating toxin in order to detoxify the toxin; and
- b) bringing the detoxified toxin into association with a second antigen, such that it functions as a mucosal adjuvant.

[0046] Specific examples of antigens useful in the present invention include HSV gD, gB and other glycoproteins; HIV gp120 and other proteins; CMV gB or gH; MCV antigens; HDV delta antigen; HAV antigens; EBV and VZV antigens; B. pertussis antigens and H. pylori antigens.

[0047] In general, the second antigen may be the immunogenic component of the vaccine intended for injection. Such vaccines, and the immunogenic components thereof, may be subunit vaccines, whole inactivated or attenuated organisms or polynucleotide vaccines.

[0048] The vaccines according to the invention may either be prophylactic (to prevent infection) or therapeutic (to treat disease after infection).

[0049] Such vaccines comprise antigen or antigens, usually in combination with "pharmaceutically acceptable carriers," which include any carrier that does not itself induce the production of antibodies harmful to the individual receiving the composition.

[0050] Suitable carriers are typically large, slowly metabolized macromolecules such as proteins, polysaccharides, polyalactic acids, polyglycolic acids, polymeric amino acids, amino acid copolymers, lipid aggregates (such as oil droplet emulsions or liposomes), and inactive virus particles. Such carriers are well known to those of ordinary skill in the art. In preferred aspects of the invention, these carriers may function as immunostimulating agents ("adjuvants"). Furthermore, the antigen may be conjugated to a bacterial toxoid, such as a toxoid from diphtheria, tetanus, cholera, H. pylori etc. pathogens.

[0051] Preferred adjuvants to enhance effectiveness of the composition include, but are not limited to: (1) aluminum salts (alum), such as aluminum hydroxide, aluminum phosphate, aluminum sulfate, etc; (2) oil-in-water emulsion formulations (with or without other specific immunostimulating agents such as muramyl peptides (see below) or bacterial cell wall components), such as for example (a) MF59™ (PCT Publ. No. WO 90/14837), containing 5% Squalene, 0.5% Tween™ 80, and 0.5% Span 85 (optionally containing various amounts of MTP-PE (see below), although not required) formulated into submicron particles using a microfluidizer such as Model 110Y microfluidizer (Microfluidics, Newton, MA), (b) SAF, containing 10% Squalene, 0.4% Tween™ 80, 5% pluronic-blocked polymer L121, and thr-MDP (see below) either microfluidized into a submicron emulsion or vortexed to generate a larger particle size emulsion, and (c) Rib™ adjuvant system (RAS), (Rib Immunochem, Hamilton, MT) containing 2% Squalene, 0.2% Tween™ 80, and one or more bacterial cell wall components from the group consisting of monophosphoryl lipid A (MPL), trehalose dimycolate (TDM), and cell wall skeleton (CWS), preferably MPL + CWS (Detox™); (3) saponin adjuvants, such as Stimulon™ (Cambridge Bioscience, Worcester, MA) may be used or particles generated therefrom such as ISCOMs (immunostimulating complexes); (4) Complete Freund's Adjuvant (CFA) and Incomplete Freund's Adjuvant (IFA); (5) cytokines, such as interleukins (e.g., IL-1, IL-2, IL-4, IL-5, IL-6, IL-7, IL-12, etc.), interferons (e.g., gamma interferon), macrophage colony stimulating factor (M-CSF), tumor necrosis factor (TNF), etc; and (6) other substances that act as immunostimulating agents to enhance the effectiveness of the composition. Alum and MF59 are preferred.

[0052] As mentioned above, muramyl peptides include, but are not limited to, N-acetyl-muramyl-L-threonine-D-isoglutamine (thr-MDP), N-acetyl-nor-muramyl-1-alanyl-D-isoglutamine (nor-MDP), N-acetylmuramyl-1-alanyl-D-isoglutamine-1-alanyl-D-glutamate-2-(1'-2'-dipalmitoyl-sn-glycero-3-hydroxyphosphoryloxy)-ethylamine (MTP-PE), etc.

[0053] The immunogenic compositions (e.g., the antigen, pharmaceutically acceptable carrier, and adjuvant) typically will contain diluents, such as water, saline, glycerol, ethanol, etc.

[0054] Additionally, auxiliary substances, such as wetting or emulsifying agents, pH buffering substances, and the like, may be present in such vehicles.

[0055] Typically, the immunogenic compositions are prepared as injectables, either as liquid solutions or suspensions; solid forms suitable for solution in, or suspension in, liquid vehicles prior to injection may also be prepared. The preparation also may be emulsified or encapsulated in liposomes for enhanced adjuvant effect, as discussed above under pharmaceutically acceptable carriers.

[0056] Immunogenic compositions used as vaccines comprise an immunologically effective amount of the antigenic polypeptides, as well as any other of the above-mentioned components, as needed. By "immunologically effective amount", it is meant that the administration of that amount to an individual, either in a single dose or as part of a series, is effective for treatment or prevention. This amount varies depending upon the health and physical condition of the individual to be treated, the taxonomic group of individual to be treated (e.g., nonhuman primate, primate, etc.), the capacity of the individual's immune system to synthesize antibodies, the degree of protection desired, the formulation of the vaccine, the treating doctor's assessment of the medical situation, and other relevant factors. It is expected that the amount will fall in a relatively broad range that can be determined through routine trials.

[0057] The immunogenic compositions are conventionally administered parenterally, e.g., by injection, either subcutaneously or intramuscularly. Additional formulations suitable for other modes of administration include oral and pulmonary formulations, suppositories, and transdermal applications. Dosage treatment may be a single dose schedule or a multiple dose schedule. The vaccine may be administered in conjunction with other immunoregulatory agents.

[0058] Examples of suitable immunostimulatory agents include interleukins, such as interleukins 1, 2, 4-7 and 12, and interferons, especially  $\gamma$ -interferon.

[0059] The invention is described hereinbelow by way of example only, with reference to the following Figures:-

#### DESCRIPTION OF THE FIGURES

[0060]

Figure 1a shows the titre of total ovalbumin specific antibody in BALE/c mice immunised *i/n* or *s/c* with either ovalbumin alone or ovalbumin together with toxin derivatives;

Figure 1b shows the titre of total toxin-specific antibody in the mice of Figure 1a;

Figure 2 shows a measurement of ovalbumin-specific IgA in nasal and lung lavages of mice injected as in Figure 1; and

Figure 3 shows the presence of tetanus toxoid-specific antibodies in the serum of BALE/c mice immunised *i/n* or *s/c* with tetanus toxin fragment C alone or together with toxin derivatives.

#### DETAILED DESCRIPTION OF THE INVENTION

[0061] Site-directed mutagenesis was used to replace the arginine residue at position seven of the A subunit of LT with lysine in order to construct a non-toxic LT mutant that could still assemble as a holotoxin with cell binding activity. The mutant protein, named LTK7, was purified and tested for ADP-ribosyltransferase and toxic activity in several assays. LTK7 was still able to bind GM1 ganglioside receptor but showed a complete loss of enzymatic activity, in agreement with published data (Lobet *et al.*, Infect. Immun. 1991; 59:2870-2879). Further, LTK7 was inactive in the mouse ileal loop assay and *in vitro* on Y1 cells, even when a dose equivalent to  $10^7$  toxic units of wild-type LT was tested (Table 1).

#### *In vivo* and *in vitro* properties of LT and of LT K-7 mutant

[0062]

TABLE 1

	LT	LT-K7	LT/LTK7
Codon in position 7 of the A subunit	CGT	AAG	-
Aminoacid in position 7 of the A subunit	Arg	Lys	-
ADP-ribosyltransferase activity of the A subunit	0.06 $\mu$ g	>> 20 $\mu$ g	<< $3.10^{-3+}$
<i>In vivo</i> in mouse ileal loop	10 $\mu$ g	>> 500 $\mu$ g/mouse	<< 0.02 **
<i>In vitro</i> toxicity on Y1 cells	10pg/ml	>> 100 $\mu$ g/ml	<< $10^{-7**}$
Binding to eukaryotic	+	+	1

\* Data published by Lobet *et al.*, and confirmed in this study

\*\* This study

>> Means that LTK7 was still enzymatically inactive or non toxic when the highest concentration shown in the table was tested.

<< Indicates that the real difference is higher than the number shown which represents the difference tested.

[0063] The ability of LTK7 to act as a mucosal adjuvant was assessed in mice. Mice were separated into groups and immunised using ovalbumin as a reporter antigen. Animals were immunised intranasally (*i/n*) or subcutaneously (*s/c*) using 10  $\mu$ g of ovalbumin alone or ovalbumin mixed with either 1  $\mu$ g CT, LT or LTK7. Mice were split into four groups of six mice. Four mice from each group were lightly anaesthetised and immunised with either 10  $\mu$ g of ovalbumin or 10  $\mu$ g

of ovalbumin with 1 µg of toxins, delivered in a total volume of 30 µl. The remaining two mice were immunised with the same amount of proteins s/c in a total volume of 100 µl. Proteins given subcut were first adsorbed to 2% Al(OH)<sub>3</sub>.

[0064] Animals were immunised on days 1, 22, 36 and 61. Sample bleeds of 100 µl were collected on day 0, 21, 35, 56 and on day 76 animals were culled by cardiac puncture.

[0065] Quantitation of antibody was estimated by ELISA. For estimation of ovalbumin-specific antibodies, 96-well EIA plates (costar) were coated overnight with 60 µg/ml of ovalbumin. Measurement of toxin-specific antibodies was performed using a GM1 capture ELISA. Toxin-specific antibodies were measured against the antigen used in the immunisations. No single toxin was used in the measurements of toxin-specific antibody from each group, and as such the titres between these groups can not be compared directly.

[0066] Sera from each group were pooled from four and two mice respectively. Samples were prepared in duplicate from a dilution of 1:50. Absorbences were read at 450 nm using the kinetic version 2.13 programme (Biotek instruments). This programme calculates the rate of change of substrate over thirty time points ten seconds apart.

[0067] ELISA titres of antibody were measured arbitrarily as the dilution of serum which gave half the maximal absorbance at 450 nm. Sera which failed to show absorbance at 450 nm 2.5 times greater than that observed with the equivalent pre-immune sera were considered negative. Results shown in Figure 1a and 1b represent the mean titre values from duplicate wells from one experiment. No significant levels of antibodies to ovalbumin above background were detected in the serum of mice immunised i/n with ovalbumin alone although mice immunised s/c efficiently sero-converted. Mice receiving ovalbumin along with either CT or LT i/n contained very high levels of anti-ovalbumin antibodies in their sera. These were equivalent to those observed when mice immunised s/c. Mice that received ovalbumin with LTK7 also showed very high levels of antibodies to ovalbumin.

[0068] The levels of anti-toxin responses in these same groups are shown in Figure 1b. All mice, including those immunised with the mutant toxin, developed high levels of antibodies to these toxin in their sera.

[0069] The local secretory antibody levels to ovalbumin were measured using both lung and nose washes (Fig. 2). In brief animals were culled by cardiac puncture and dissected so that the trachea was exposed. An ultra-thin pipette was then inserted into a small nick in the trachea. Lung washes were collected by repeated flushing and aspiration of 1.5 ml of 0.1% bovine serum albumin (Sigma), in PBS, into the lungs. Nose washes were collected by flushing 1 ml of 0.1% BSA in PBS through the nasal cavity.

[0070] Ovalbumin-specific IgA antibodies were measured by ELISA using an anti-mouse alpha-chain-specific conjugate antibody (Serotec). Samples were prepared from individual animals and columns in this figure represent the mean rate of change of substrate, using kinetic, for four and two mice immunised i/n and s/c respectively. The figures are constructed using the raw absorbance data at a dilution of 1:3 with respect to lung washes. These correspond to titres of between 1:2 and 1:6 for nose washes and between 1:70 and 1:120 for lung washes. These titres were calculated using the method described above. Mice immunised s/c or i/n with ovalbumin alone contained no detectable ovalbumin-specific IgA in the washes sampled. All individual mice immunised with ovalbumin in combination with CT, LT or LTK7, showed detectable levels of anti-ovalbumin IgA. Thus both a local and systemic anti-ovalbumin response are detectable in these animals.

[0071] In the face of these encouraging experiments with ovalbumin the immunisation was repeated using Fragment C, a 50,000 dalton, non-toxic portion of tetanus toxin which had been expressed in and purified from the yeast *Pichia pastoris*. Mice were immunised either s/c or i/n with Fragment C alone or mixed with individual samples of either LT or LTK7. Mice were separated into four groups of ten mice and four groups of five mice. Ten mice were immunised i/n with a) 10 µg of fragment C alone; b) 10 µg of fragment C + 1 µg of LT; c) 10 µg of fragment C + 1 µg of LTK7 and d) PBS only, all in a final volume of 30 µl. Five mice were immunised i/n with a) 1 µg of LT and b) 1 µg of LTK7. The remaining two groups of mice were immunised s/c with either no protein or 10 µg of fragment C in a dose volume of 100 µl. These vaccines were prepared as described in Figure 1. Animals were immunised on day 1 and 22. Sample bleeds of 100 µl were collected on day 0, 21 and 35. Fragment C-specific antibodies were measured by ELISA using tetanus toxoid (10 µg/ml) as the coating antigen. Sera from each group were pooled. Samples were prepared in duplicate from a dilution of 1:50. ELISA titres were calculated as described above. Mice immunised s/c with Fragment C efficiently sero-converted producing high levels of anti-Fragment C antibodies (Fig. 3). Mice immunised i/n with Fragment C alone showed no significant sero-conversion. However mice immunised with Fragment C combined with LT or LTK7 showed high levels of anti-Fragment C antibodies in their sera (Fig. 3). Since mice that sero-convert to Fragment C can be protected against toxin challenge the groups were challenged with active tetanus toxin. All mice immunised s/c with Fragment C alone were protected whereas all mice immunised i/n were highly susceptible. All mice i/n immunised with Fragment C combined with either LT or LTK7 survived the challenge (Table 2).

TABLE 2

	Serum anti-Fragment C	Deaths
LT	—	10/10
LTK7	—	10/10
LTK7 + Fragment C	++	0/10
Lt + Fragment C	++++	0/10
Fragment C	+/-	10/10
The titre of anti-Fragment C antibodies in the serum of mice was on average about 1/3,000 in mice vaccinated with the K7 mutant + Fragment C and 1/12,000 for LT + Fragment C.		

[0072] These experiments show that protective immunity against tetanus can be achieved using a non-toxic LT mutant as adjuvant and that mucosal immunisation with this molecule can generate both local secretory and systemic immune response to the toxin and co-administered bystander antigens.

#### Claims

1. A pharmaceutical composition comprising a non-toxic mucosal adjuvant in admixture with a second antigen, characterised in that said non-toxic mucosal adjuvant is a detoxified bacterial ADP-ribosylating toxin having a mutant A subunit, provided that said non-toxic mucosal adjuvant is not a non-toxic double mutant form of pertussis toxin.
2. A pharmaceutical composition according to claim 1, wherein said non-toxic mucosal adjuvant is a detoxified mutant of CT or LT.
3. A pharmaceutical composition according to claim 1 or claim 2, wherein the non-toxic mucosal adjuvant comprises one or more amino acid additions, deletions or substitutions in the A subunit of the holotoxin.
4. A pharmaceutical composition according to claim 3, wherein the non-toxic mucosal adjuvant is LT-K7.
5. Use of a detoxified bacterial ADP-ribosylating toxin having a mutant A subunit as a mucosal adjuvant in the preparation of a composition for mucosal administration, provided that said non-toxic mucosal adjuvant is not a non-toxic double mutant form of pertussis toxin.
6. Use according to claim 5, wherein the composition is a vaccine.
7. Use according to claim 6, wherein the vaccine is for use in prophylactic or therapeutic applications.
8. Use according to any one of claims 5 to 7, wherein the composition further comprises a second antigen.
9. The use of a mucosal adjuvant as defined in any one of claims 1 to 4 during the manufacture of a vaccine, provided that said non-toxic mucosal adjuvant is not a non-toxic double mutant form of pertussis toxin.
10. The use of claim 10, wherein the vaccine is for oral or intranasal administration.
11. A pharmaceutical composition comprising a non-toxic mucosal adjuvant and a second antigen for simultaneous, separate or sequential administration, characterised in that said non-toxic mucosal adjuvant is a detoxified bacterial ADP-ribosylating toxin having a mutant A subunit, provided that said non-toxic mucosal adjuvant is not a non-toxic double mutant form of pertussis toxin.
12. A pharmaceutical composition comprising a non-toxic mucosal adjuvant and a second antigen for simultaneous administration when combined in a single vehicle, carrier or particle, characterised in that said non-toxic mucosal adjuvant is a detoxified bacterial ADP-ribosylating toxin having a mutant A subunit, provided that said non-toxic



mucosal adjuvant is not a non-toxic double mutant form of pertussis toxin.

13. A method for the manufacture of an adjuvanted vaccine, comprising the steps of:

(a) performing site-directed mutagenesis in the A subunit of a bacterial ADP-ribosylating toxin in order to detoxify the toxin; and

(b) bringing the detoxified toxin into association with a second antigen, such that it functions as a mucosal adjuvant,

provided that said non-toxic mucosal adjuvant is not a non-toxic double mutant form of pertussis toxin.

14. A pharmaceutical composition according to any one of claims 1, 2, 3, 4, 11 or 12, in which the antigen is enclosed in slow-releasing microspheres.

# Patentansprüche

1. Arzneimittel, umfassend ein nicht-toxisches Mucosa-Adjuvans im Gemisch mit einem zweiten Antigen, dadurch gekennzeichnet, daß das genannte nicht-toxische Mucosa-Adjuvans ein entgiftetes bakterielles ADP-ribosylierendes Toxin mit einer mutierten A-Untereinheit ist, mit der Maßgabe, daß das nicht-toxische Mucosa-Adjuvans keine nicht-toxische Doppelmutanten-Form von Pertussis-Toxin ist.

2. Arzneimittel nach Anspruch 1, wobei das nicht-toxische Mucosa-Adjuvans eine entgiftete Mutante von CT oder LT ist.

3. Arzneimittel nach Anspruch 1 oder 2, wobei das nicht-toxische Mucosa-Adjuvans eine oder mehrere Aminosäureergänzungen, -deletionen oder -substitutionen in der A-Untereinheit des Holotoxins umfaßt.

4. Arzneimittel nach Anspruch 3, wobei das nicht-toxische Mucosa-Adjuvans CT-K7 ist.

5. Verwendung eines entgifteten bakteriellen ADP-ribosylierenden Toxins mit einer mutierten A-Untereinheit als Mucosa-Adjuvans für die Herstellung einer Zusammensetzung zur Mucosa-Anwendung, mit der Maßgabe, daß das nicht-toxische Mucosa-Adjuvans keine nicht-toxische Doppelmutanten-Form von Pertussis-Toxin ist.

6. Verwendung nach Anspruch 5, wobei die Zusammensetzung ein Impfstoff ist.

7. Verwendung nach Anspruch 6, wobei der Impfstoff für prophylaktische oder therapeutische Anwendungen verwendet wird.

8. Verwendung nach einem der Ansprüche 5 bis 7, wobei die Zusammensetzung ferner ein zweites Antigen umfaßt.

9. Verwendung eines Mucosa-Adjuvans, gemäß der Definition in einem der Ansprüche 1 bis 4, während der Herstellung eines Impfstoffs, mit der Maßgabe, daß das nicht-toxische Mucosa-Adjuvans keine nicht-toxische Doppelmutanten-Form von Pertussis-Toxin ist.

10. Verwendung nach Anspruch 10 wobei der Impfstoff für orale oder intranasale Verabreichung bestimmt ist.

11. Arzneimittel, umfassend ein nicht-toxisches Mucosa-Adjuvans und ein zweites Antigen zur gleichzeitigen, getrennten oder aufeinanderfolgenden Verabreichung, dadurch gekennzeichnet, daß das nicht-toxische Mucosa-Adjuvans ein entgiftetes bakterielles ADP-ribosylierendes Toxin mit einer mutierten A-Untereinheit ist, mit der Maßgabe, daß das nicht-toxische Mucosa-Adjuvans keine nicht-toxische Doppelmutanten-Form von Pertussis-Toxin ist.

12. Arzneimittel, umfassend ein nicht-toxisches Mucosa-Adjuvans und ein zweites Antigen zur gleichzeitigen Verabreichung, wenn in einem einzigen Vehikel, Träger oder Partikel kombiniert, dadurch gekennzeichnet, daß das nicht-toxische Mucosa-Adjuvans ein entgiftetes bakterielles ADP-ribosylierendes Toxin mit einer mutierten A-Untereinheit ist, mit der Maßgabe, daß das nicht-toxische Mucosa-Adjuvans keine Doppelmutanten-Form von Pertussis-Toxin ist.

13. Verfahren zur Herstellung eines Adjuvans-Impfstoffes, folgende Schritte umfassend:

a) Durchführung einer ortsspezifischen Mutagenese in der A-Untereinheit eines bakteriellen ADP-ribosylierenden Toxins, um das Toxin zu entgiften,

b) Assoziation des entgifteten Toxins mit einem zweiten Antigen, so daß es als Mucosa-Adjuvans fungiert, mit der Maßgabe, daß das nicht-toxische Mucosa-Adjuvans keine nicht-toxische Doppelmantanten-Form von Pertussis-Toxin ist.

14. Arzneimittel nach einem der Ansprüche 1, 2, 3, 4, 11 oder 12, in dem das Antigen in langsam freisetzende Mikrosphären eingeschlossen ist.

## Revendications

1. Composition pharmaceutique comprenant un adjuvant non toxique pour les muqueuses mélangé à un second antigène, caractérisée en ce que ledit adjuvant non toxique pour les muqueuses est une toxine ADP-ribosylante bactérienne détoxifiée ayant une sous-unité A mutante, à condition que ledit adjuvant non toxique pour les muqueuses ne soit pas une forme mutante double non toxique de la toxine de pertussis.

2. Composition pharmaceutique selon la revendication 1, dans laquelle ledit adjuvant non toxique pour les muqueuses est un mutant détoxifié de CT ou LT.

3. Composition pharmaceutique selon la revendication 1 ou 2, dans laquelle l'adjuvant non toxique pour les muqueuses comprend une ou plusieurs additions, délétions ou substitutions d'acides aminés dans la sous-unité A de l'holotoxine.

4. Composition pharmaceutique selon la revendication 3, dans laquelle l'adjuvant non toxique pour les muqueuses est le LT-K7.

5. Utilisation d'une toxine ADP-ribosylante bactérienne détoxifiée ayant une sous-unité A mutante comme adjuvant mucosal dans la préparation de la composition pour l'administration mucosale, à condition que ledit adjuvant non toxique pour les muqueuses ne soit pas une forme de mutant double non toxique de toxine de pertussis.

6. Utilisation selon la revendication 5, dans laquelle la composition est un vaccin.

7. Utilisation selon la revendication 6, dans laquelle le vaccin est utilisé pour des applications prophylactiques ou thérapeutiques.

8. Utilisation selon l'une quelconque des revendications 5 à 7, dans laquelle la composition comprend en outre un second antigène.

9. Utilisation d'un adjuvant pour muqueuses tel que défini dans l'une quelconque des revendications 1 à 4, pour la fabrication d'un vaccin, à condition que ledit adjuvant non toxique pour les muqueuses ne soit pas une forme de mutant double non toxique de toxine de pertussis.

10. Utilisation de la revendication 10, dans laquelle le vaccin est destiné à l'administration orale ou intranasale.

11. Composition pharmaceutique comprenant un adjuvant non toxique pour les muqueuses et un second antigène pour administration simultanée, séparée ou successive, caractérisée en ce que ledit adjuvant non toxique pour les muqueuses est une toxine ADP-ribosylante bactérienne détoxifiée ayant une sous-unité A mutante, à condition que ledit adjuvant non toxique pour les muqueuses ne soit pas une forme mutante double non toxique de la toxine de pertussis.

12. Composition pharmaceutique comprenant un adjuvant non toxique pour les muqueuses et un second antigène pour administration simultanée lorsqu'ils sont combinés en un unique véhicule, support ou particule, caractérisée en ce que ledit adjuvant non toxique pour les muqueuses est une toxine ADP-ribosylante bactérienne détoxifiée ayant une sous-unité mutante A, à condition que ledit adjuvant non toxique pour les muqueuses soit une forme mutante double non toxique de la toxine de pertussis.

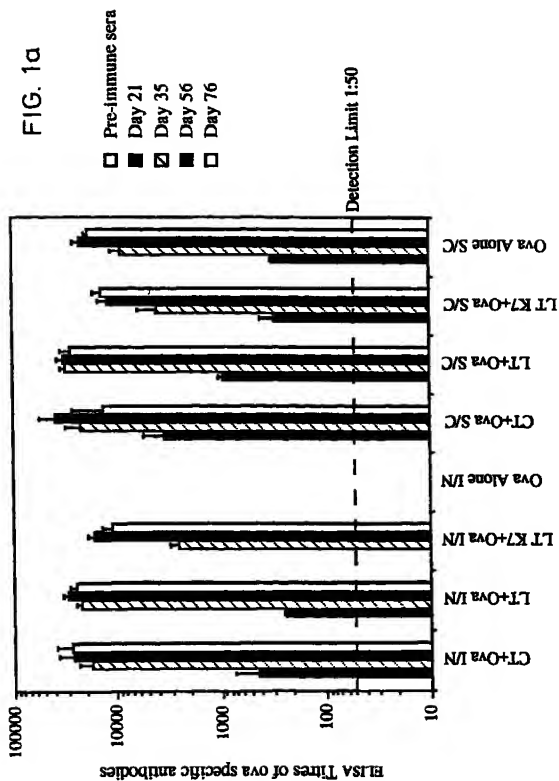
13. Procédé de fabrication d'un vaccin avec adjuvant, comprenant les étapes de :

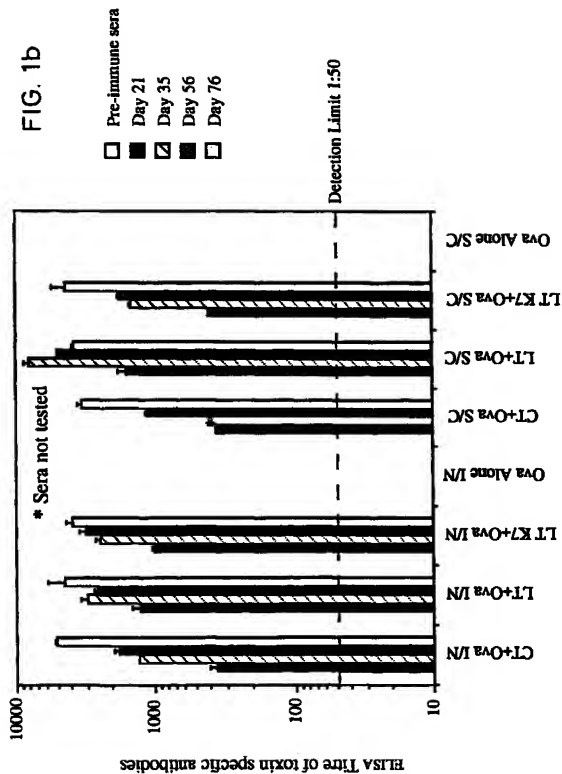
(a) réalisation d'une mutagenèse dirigée dans la sous-unité A d'une toxine ADP-ribosylante bactérienne afin de détoxifier la toxine ; et

(b) mise en association de la toxine détoxifiée avec un second antigène, de manière qu'elle fonctionne comme adjuvant pour les muqueuses, à condition que ledit adjuvant non toxique pour les muqueuses ne soit pas une forme mutante double non toxique de la toxine de pertussis.

14. Composition pharmaceutique selon l'une quelconque des revendications 1, 2, 3, 4, 11 ou 12, dans laquelle l'antigène est enfermé dans des microsphères à libération lente.

FIG. 1a





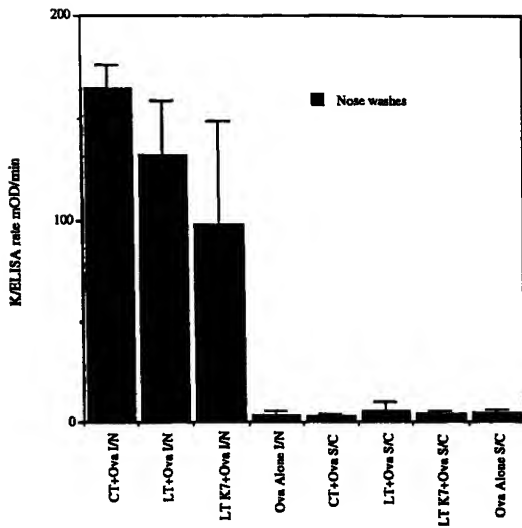


FIG. 2 (i)

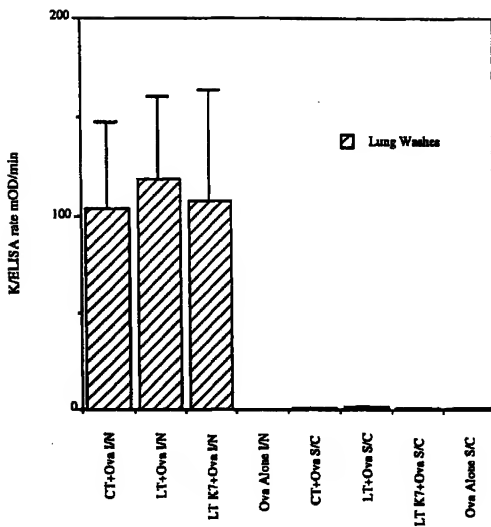


FIG. 2(ii)

FIG. 3

